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Baby and The Brain: Advances in Child Development

Janet A. DiPietro
Department of Population and Family Health Sciences, School of Public Health, Johns Hopkins University, Baltimore, Maryland 21205; e-mail: jdipietr@jhsph.edu

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■ **Abstract** As child morbidity and mortality declined during the twentieth century, a corresponding increase occurred in the relevance of child psychological well-being to public health. Evidence of this trend is the proliferation of programs intended to ameliorate conditions that place children in jeopardy of poor developmental outcome. Most recently, neurobiologic information on brain function and structure has been used to promote strategies for optimizing child development. This review will evaluate the current state of knowledge relating early child development to brain research and illustrate the potential misuse of this information. It will also suggest the following: (*a*) the extrapolation of neuroscience results to early academic and social enrichment programs obscures the magnitude of potential effects of these programs relative to the vast burden of risk imposed by poverty, and (*b*) an emphasis on intellectual functioning misses the most compelling evidence on the role of the early social environment in mediating establishment of neural networks that regulate a child's response to stress and capacity for self-control.

PUBLIC HEALTH CONTEXT OF EARLY DEVELOPMENT

Interest in the cognitive, social, and emotional development of children is a societal luxury. As child morbidity and mortality declined during the twentieth century, a corresponding increase occurred in the amount of knowledge generated about child development (32), coupled with a proliferation of programs aimed at ameliorating conditions that place children in jeopardy of poor developmental outcome.

The importance of the mental and physical well-being of children to public health is increasingly apparent. Developmental science has not been well integrated into policy or programmatic application, although there are indications that synthesis is emerging (52). This reconciliation is difficult to effect because the research literature can and has yielded results that fail to support popular policies and programs.

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Recently, interest in the underlying neurobiologic mechanisms that drive development has burgeoned, as investigators seek basic information about both normal and atypical development. In the 1990s a small number of reports using recent neuroscience technologies, including functional magnetic resonance imaging (fMRI) and positron emission technology (PET), were at the basis of a much-heralded public campaign promoting the role of early experience in brain development. The distillate of the current findings about early brain development is this: Activation of neurons serves to direct the neuroarchitecture of connections within the developing brain, and activation is promulgated in part by the experiences to which infants and young children are exposed. Features of neuroanatomical development, particularly the density of synapses, appear to fluctuate with age in a manner that corresponds roughly with maturational stages and abilities. The first three years of life have been identified as a period of particularly rapid development of cortical structure and function.

This information has provided the impetus for proposal of numerous strategies to promote optimal brain development, from encouraging parents to read aloud to their young children each day to advocating for federal funding to begin Head Start and related programs at earlier ages. However, academic debate exists over whether the current state of knowledge significantly informs decisions concerning public policy (11) or provides no meaningful information at this time (5). While public and professional discourse about factors that foster optimal child well-being is useful in general, there is a fundamental irony in the situation: the neuroscience techniques and handful of often-cited studies that have galvanized public interest have not been clearly linked, at this time, with child behavior or development. Conversely, the most robust information about early brain development has been available long before the recent campaign, and most of this information has been gleaned by studies of child behavior, not brain.

Understanding of how features of brain function or neuroanatomy may be related to behavior is rudimentary at best, in part because of disciplinary boundaries between neuroscience and developmental psychology, although both share common goals (38). Thus, much of what is included under the rubric of "the new brain research" is neither new nor based on technologies which image the brain. The current review will present and evaluate the nature of the evidence as it relates to potential public health application.

BRAIN DEVELOPMENT

Prior to birth, neurons proliferate, migrate, and aggregate, providing the "hardware" of the developing brain. Although the entire antenatal period is critical for central nervous system growth and development, its inclusion has been conspicuously absent from the current campaign. Neuronal proliferation before birth has been estimated at an average rate of 250,000 per minute (13). The intrauterine environment provides experiences that exert influences on fetal behavior, which in turn advance neurologic development (47). The developing structure

of the nervous system before birth provides the substrate for the ultimate neuronal circuitry, which is driven by genetic and experiential processes before and after birth.

The neonate has an estimated 100 billion neurons but relatively few synapses, or connections, among them. Much of this neuronal "interconnectivity" develops after birth, through processes of synapse formation, myelination, apotosis, and selective elimination of previously established synapses (24, 36). The period of neuronal proliferation was commonly accepted to be completed at birth until the recent discovery of newly generated neurons in the hippocampus of adults, although the rate of neurogenesis is low relative to the total number (16).

At birth, the neonatal brain weighs approximately 25% of adult size. The brain undergoes rapid growth and development in the first three years of life: myelination and dendritic growth result in a tripling of brain weight during this time. Knowledge of the developmental trajectory of synaptogenesis in humans is primarily based on autopsy data (30). Synaptogenesis is profuse, so that by age three synaptic density is the highest at any point in life and at least 50% greater than in the adult brain. The period of peak synaptogenesis has been established in different regions of the brain. For example, synaptic density in the prefrontal cortex accelerates beginning at eight months and attains maximal density at two years. Synaptogenesis throughout the cortex plateaus after this period until age 12 or 13 (41).

At or near puberty, process elimination or "pruning" of established synapses accelerates until attaining adult levels, at which time synaptic densities are roughly comparable to early infancy. The trajectory of synaptogenesis in humans also corresponds to that observed during the life span of nonhuman primates (18).

Process elimination is selective and based, in part, on early environmental factors and experiences (2). Neural development is driven by genetic influences as well as experiential. The nature-versus-nurture distinction has been further blurred by the gradual appreciation of the epigenetic role of the environment in regulating genetic transcription. The term "experience-expectant" has been proposed to categorize neural networks that are established by exposure to stimuli or experiences that are conspecific. In contrast, experience-dependent development is a function of the idiosyncratic stimuli available to individuals (19).

The old postulate that "neurons that fire together, wire together" remains the underlying principle regarding the manner in which experiences affect neural networking (22). Thus, learning and development during childhood and beyond can be regarded primarily as a function of the elimination of unnecessary associations and maintenance of those that are used. The metaphor of a sculptor chipping away at portions of the existing stone to yield the finished product has been invoked to describe this process (31).

There has been much speculation that developmental changes in synaptogenesis mediate normal acquisition of cognitive and motoric developmental milestones (40). PET scan images of glucose consumption in the brain reveal a corresponding pattern of peak activity at three years of age, at which time glucose consumption in the cerebral cortex is estimated at twice the adult rate. After birth, the foci of

utilization progress from subcortical to higher structures. Metabolism plateaus between ages 4 and 10, with a gradual decline to adult levels by late adolescence (10).

While it is true that the trajectory of synaptogenesis corresponds to that of brain metabolism, and both parallel the emergence of cognitive and behavioral capabilities, the causal and directional relations among the three are not clear. Single functional or structural indicators of the brain, such as synaptic density or glucose uptake, should not be relied on as indicators of the functioning of the "mind." Moreover, the rapid rise and early peak in aspects of brain structure and function should not be interpreted as an indication that the ability to learn is greatest in the third year of life. The brain does not mature functionally until late adolescence or later, when high levels of linguistic and analytic competence are attained. A variety of neuroanatomical factors have been proposed to mediate this period of development as well, including synaptic density and efficiency, speed of axonal transmission as a result of myelination, and adaptations in reorganization of neural circuitry (41). Indeed, the tenor of the current research into brain function during adolescence and adulthood is characterized by the affirmation of plasticity and adaptability throughout life.

STIMULATION AND DEPRIVATION

The core issue relating the cursory information about brain development to public health application involves the consequences of early experiences on subsequent development and the efficacy of providing compensatory experiences under conditions of deprivation. The classic study of the effect of lack of stimulation during a critical period in establishing binocular vision in cats (29) is a powerful example of experience-expectant processes. In humans, case studies of individuals who become incapable of producing coherent language because they were bereft of hearing language as children, as a result of deafness or disordered social relations, provide an analogue to this phenomenon. Such instances of extreme deprivation are rare, but the importance of early experience in canalizing neural development has also been provided in studies of normal development. For example, beginning in the first year of life, exposure to linguistic features of a native language is associated with elimination of perceptual discrimination of sounds not common to that language (33).

It has been assumed that this process involves decay of unused neural connections. Indeed, most of what is known about the function and development of childrens' brains has been inferred from studies of perception, cognition, and affect, not neuroanatomy. This approach reveals the pervasive assumption that observable behavior is a manifestation of the underlying neural substrate and, ultimately, the final instantiation of theories concerning brain function (38). The recent implementation of brain imaging technologies to confirm and elaborate these inferences provides an important refinement of developmental epistemology, as do

other efforts directed at the molecular and genetic level. These techniques can also serve to enhance diagnosis of neurological conditions when behavioral manifestations are multi-determined. For example, fMRI has revealed that compared to controls, children with stimulant-sensitive ADHD (attention deficit hyperactivity disorder) display differences in activity in the basal ganglia during both baseline and medicated conditions (50). This observation has significant potential in refinement of diagnosis of ADHD to exclude individuals who display attentional dysregulation that has other sources.

Empirical validation of the relation between neuroanatomy, brain function, and behavior is difficult, particularly within the normal range. Instead, investigations often focus on comparing normally developing individuals to those with highly enriched or extremely deprived experiences. For example, magnetic source imaging of the brain loci associated with finger dexterity reveal reorganized and enhanced cortical representation in areas controlling the left hand of highly skilled adult string players (15). Individuals who began musical training prior to the age of 12 display the greatest cortical response in the focused areas. Similarly, adult braille readers display topographical differences in cortical representation of their fingers (48). Data of this nature provide neural confirmation of peripheral dexterity and insight into the brain's integration of sensorimotor experiences. However, these "experiments in nature" are not controlled intervention studies, and associations may be subject to a variety of confounding factors, including genetic predisposition. In particular, studies of adults can provide little information supporting or disconfirming the primacy of early childhood because duration and age of exposure are confounded. However, ethical and procedural issues currently preclude the routine use of imaging techniques on normally developing infants and young children. PET scans necessitate injection of a radioactive marker, while fMRIs require a prolonged period of inactivity in a confined space.

Individual differences in social and intellectual development arise through intrinsic and experience-dependent processes. In contrast to experience-expectant processes, the former includes the vagaries in experiences that distinguish one individual from another. Development across cognitive, socio-emotional, language, and motor domains is highly interrelated. Thus, enrichment or deprivation provided in one developmental modality can affect development in others. For example, prelocomotor infants provided with experience with walkers develop wariness of height earlier than those without mobility experience (3). Studies of maltreated children using electroencephalography (EEG), a more common but distal measure of brain activation detected at the scalp, indicate diffuse cognitive and perceptual effects. Maltreated children process information about adult facial expressions of emotions differently, confirming behavioral observations of responses (40).

Animal models of the effects of stimulation are based on studies in which offspring are reared in "enriched" conditions that include exposure to stimuli that encourage active exploration. This research has yielded long-standing results that immature animals, typically rats, raised in the more complex environments have greater brain weights and more adaptive learning behaviors than those that were

not raised in complex environments (45). Although these data are commonly used to support enrichment programs for children, application is not straightforward. Significant comparisons in such studies are typically those between animals reared in social isolation and those reared in social cages which have stimuli designed to provide them with the types of experiences they would normally encounter outside a laboratory environment (5). Stimulation and deprivation are generally regarded as opposites along a continuum of optimality, but they are not. For example, in the 1970s, pre-term infants in neonatal intensive care units were considered to be "under-stimulated" and in need of compensatory stimuli to promote development. Upon investigation and reflection, it became clear that the reverse was true: the intensive-care environment provided excessive stimulation and environmental mitigation was necessary. Similarly, "deprived" neighborhoods provide substantial stimulation to children reared there, but may not provide enough developmentally appropriate stimuli. The term "developmentally appropriate" is often used to characterize stimuli that have sensory or affective properties that are consistent with developmental capabilities and thus most likely to be appropriately incorporated into neural processes.

Plasticity Beyond Infancy

The immaturity of the human brain at birth is key to the high level of postnatal learning necessary to transmit our complex culture. The primary locus of the capabilities that distinguish humans from other species, the cerebral cortex, is among the most immature regions of the brain at birth. Whether early brain injury is associated with functional impairment in adulthood depends on many factors, including locality of the lesion and the behavioral domain affected (31). Whether the first three years constitute a "critical period" for all subsequent processes and is qualitatively different from other stages remains questionable. There are compelling reasons to think that it is not. Critical periods have been identified for only specific aspects of motor and sensory function, not for the types of intellectual and affective processes that characterize most of human development (5). Much of the data used to support the concept of a critical period is based on the observed trajectory of synaptogenesis and metabolism. However, sensorimotor development appears to require only a minimum input of species-expectant experiences, and there is no evidence that altering the experiences or environment of a normally developing child will affect this pattern (5).

On the contrary, developmental sciences are generating findings about the plasticity of the brain during all periods of life, including adolescence and adulthood, that are difficult to reconcile against the discourse promoting the primacy of infancy in brain development. For example, a recent case study describes rapid acquisition of language after left hemispherectomy at age nine by a child who was previously without speech (51). Development is notorious for its self-righting quality, such that after biologic or environmental conditions are restored to normal, early stunting is followed by accelerated developmental rate until catch-up is attained. Lack

of recognition of developmental plasticity beyond early childhood is a hidden hazard in the emphasis on infancy. Children who have weathered difficult physical and social environments in infancy may be regarded as permanently brain damaged, as was the case with the myth of the crack cocaine baby (35). In the late 1980s, false alarms were sounded about the devastating effects of antenatal cocaine exposure on development before sufficient data were accrued. Policy responses ranged from discussion of building special schools to educate cocaine-exposed children to legal consequences for women who used cocaine during pregnancy. Prospective adoptive families were cautioned against the burden of raising cocaine-exposed children. Today, despite rigorous investigation, few effects of cocaine exposure on infant or child development have been detected. Effects, when detected, are subtle and can be considered trivial relative to the risk factors introduced to the postnatal environment by maternal drug use. The "crack baby" should remain an example of the damaging effects that over-interpretation of research findings can have, and reinforce caution when simplifying complex studies to the level necessary to capture public and political interest.

Deprivation: The Case of the Romanian Orphans

The plight of Romanian orphans, reared under conditions of severe social deprivation, has been used recently to explore the detrimental effects of early deprivation on the developing brain. Functional brain anomalies, particularly involving hypoactivation in the frontal cortex, have been reported from PET scans conducted on a small number of adoptees. Again, because such studies are not subject to experimental controls, confounding factors (e.g. abandonment due to existing conditions) may jeopardize interpretations (28). Nonetheless, an accumulating body of behavioral data on these children is consistent in finding that the shorter the period of institutionalization, the better the developmental and socio-emotional outcome. By preschool age, children adopted before six months effectively catch up to normal controls in growth and cognitive ability. However, the behavioral resilience observed in children adopted at later ages when provided a normal environment is as striking as the adverse consequences (28, 46). These findings fail to support the primacy of early infancy for subsequent development, and reinforce the plasticity of the developing brain in response to changing environmental circumstances. Popular reports of these children as brain damaged are not supported by behavioral data, but can dissuade prospective adoptive parents and affect the nature of assistance provided by public agencies. Of course, this is not to imply that early deprivation is trivial: the consequences on growth and development for children who remain in deprived conditions are pernicious. However, once these children are removed from extreme circumstances and exposed to normal social and physical environments, persistent effects are subtle and often relegated to the socio-emotional domain. In particular, individual differences in the ability to form emotional attachments once adopted appears key to normal cognitive and social development (8). The factors mediating resilience in children who are exposed to

social and biologic risk factors has been an area of investigation for many years, but the manner in which protective factors exert influence are not well defined. Brain imaging technologies may contribute to understanding the mechanisms that generate resilience under conditions of risk.

Do Babies Need Mozart?

Despite the complex scientific issues in interpretation, the popularization of the "new brain research" has already had significant policy and programmatic effects. A well-known example of a policy generated by this campaign is the Georgia state legislature's 1998 mandate for distribution of a recording of classical music to all newborn infants with the explicit goal of stimulating intellectual development. Other states have quickly followed suit despite the fact that there have been no studies on either behavioral or neuroanatomical effects of listening to music in infancy or childhood. The "Mozart effect," at the core of this policy, is a term coined to describe a finding that listening to classical music is associated with a short-term increase in a spatial reasoning task in adults (42). The effect has not been well replicated, although there is a report of a similar effect using a different musical genre (i.e. a recording by pop musician Yanni) (44), thus diluting the primary hypothesis concerning the unique spatiomathematical properties of music crafted by Mozart.

Recently, a meta-analysis of 16 studies concluded that the Mozart effect in adults is not a robust phenomenon and yields no significant effects on IQ (7a). Somewhat surprisingly, the study commonly cited to support a Mozart effect in children (43) did not include listening to music at all. Daily keyboard and singing lessons were provided to 34 preschoolers for 6 to 8 months. The intervention was associated with an increase in performance of approximately one standard deviation on only one of six spatial tasks. This modest effect followed this fairly intensive intervention that included active participation, not just passive exposure to music. Music may have many benefits for young children, but effects on intellectual development are not supported by existing data. However, the political appeal of "making babies smarter" cannot be overestimated and has resulted in a policy bearing no resemblance to the research base. Although it can be argued that distributing music to parents of newborns is an inexpensive, benign policy response that can do no harm, such organized responses can have hidden costs if they convey the message that good cognitive outcomes can be generated simply by turning on a tape or if they give the illusion that something is being done to the exclusion of more complex, costly, and potentially effective interventions.

Early Intervention Programs

Before the emergence of the interest in infants' brains, there was consensus that interventions directed at compensating for deprivation experienced by impoverished and otherwise at-risk children must be early, intensive, and lengthy. Early intervention programs are typically extolled as public policy investments with high return

in terms of child development and academic success. Unfortunately, the two most well-designed, rigorously implemented, and broadly evaluated studies of early intervention programs have yielded discouraging results. Both the Abecedarian (6) and Infant Health and Development Projects (IHDP) (4) were randomized trials providing intensive social and academic center-based curricula beginning at four months and one year, respectively, to children with biologic or social risk factors. The latter program continued to age three, the former through age five with a subset of participants receiving a less intensive, school-based intervention after this time. Significant effects on IQ in the age-three group were credited to both programs, with differences between the control and intervention groups ranging from 9 to 14 points. However, once the intervention was withdrawn, both experimental groups displayed a decline in performance to near-control levels. By age five through the latest report of follow-up at age eight, the IHDP program was not associated with significant differences in IQ. Sample selection in that program was targeted at low-birthweight babies, and a subgroup analysis of infants who were heavier at birth (2001–2500 g) revealed a four-point IQ difference between the intervention and control groups. At ages 12 and 15, participants in the preschool component of the Abecedarian project displayed IQ levels 5 points higher than controls; the school-age intervention had no effect (7). The ineffectiveness of the school age program should not be considered as support for early programs versus later ones; the school-age intervention was of relatively low intensity given the constraints of the public school system and in contrast to the infant intervention. In the Abecedarian project, achievement tests revealed similar effects on academic performance commensurate with the difference in IQ; neither program yielded significant effects on grade retention or special education placement. Despite the failure to demonstrate sustained effects after the intervention programs were withdrawn, these intervention programs are typically heralded as successes and support for intervening in the first three years of life.

Other considerations temper enthusiasm. A differential of five IQ points represents less than one-third standard deviation of norm-referenced IQ scores, and is of little clinical significance for individual children. These modest effects were produced by university-based child development programs that incorporated the best available information on child development and adhered to stringent educational criteria, such as low teacher-to-child ratios. Thus, they bear little resemblance to existing or future preschools in impoverished communities. The IHDP was sponsored by 5 federal agencies at a cost of $33 million, although only 377 children of the sample of 985 were stratified to the intervention program. The cost per child in one study site (i.e. Miami) was estimated at $15,000 per year. It is reasonable to conclude that the findings produced by these two programs represent the maximum potential effects of early intervention programs.

The more serious, and least publicized, concern is the absolute value of scores for children in both the control and intervention groups of the Abecedarian project, which selected participants based on an index of high social risk centering around poverty. In addition to the nonintervention control group, a secondary control

was drawn from the classrooms of the target subjects. The mean IQ at 8 years for that group was 110, as compared to 91 for the Abecedarian participants (6). The significance of a differential of nearly 20 points cannot be understated and is directly relevant to academic achievement. Supposing that the IQ differential generated by the Abecedarian program was more substantial than it is, the fact that these children remain at such a significant disadvantage to their classmates reveals the devastating limitations of such compensatory efforts.

Continuing emphasis on finding the "right" early intervention program which can capitalize on the features of the developing brain during the first three years may be a distraction that we can no longer afford. Poverty interacts, both figuratively and statistically, with all biological and social risks factors, such that poor children experience "double jeopardy" (39). That is, children born in poverty are both more likely to be exposed to risk factors for development and more likely to be adversely affected by that risk factor. For example, not only is prematurity more common in low income populations, but the developmental outcomes for pre-term infants born into poverty, after adjusting for social class effects, are significantly worse than for middle-class infants born at the same gestational age and birth weight. A similar phenomenon exists for lead exposure. Turning attention to the mechanisms which moderate the effects of social class on child well-being may yield more suitable intervention targets. There are indications that this pursuit has begun in earnest, evidenced by an increasing number of conferences and meetings by diverse academic and policy organizations (e.g. New York Academy of Sciences, Environmental Protection Agency) focused on understanding the mechanisms which generate social class effects.

Maternal education has long been known to be the single best predictor of child developmental outcome. Social class differences exist in the neurobehavioral development of fetuses from mid-pregnancy (14), suggesting developmental disadvantage may begin before birth. The mechanisms through which maternal education affects child IQ and other outcomes are not well known, although biologic influences as well as experiential ones are likely. One of the most well-recognized features of the postnatal home environment involves the use of language and infant-directed speech. In the first year of life children reared in homes of high socio-economic status (SES) have three times as much speech directed to them as do low SES children. This disparity widens during subsequent years when child language acquisition is most rapid. Across social class groups, the structure and complexity of language used in the home, as well as the emotional content, are significantly associated with IQ by age three (21). Characteristics of language that promote intellectual development include diversity in grammar, syntax, and vocabulary. Moreover, conversational styles that include the use of explanatory material rather than commands, are contingent upon the child's activities, and elaborate upon the child's spoken words or infant's nonverbal utterances are also features of an optimal linguistic environment. Differences in parenting styles and strategies also serve to mediate social class disparity in child developmental outcomes. For discussion and a review of the processes that may direct this relationship, readers

are directed to McLoyd (35a). The ultimate strategies recommended to mitigate the negative effects of low parental education on child development will likely be complex and controversial, but it can be surmised that playing classical music will not be among them.

As center-based interventions targeted toward children fail to produce expected results, interest has shifted toward providing families with programs that may benefit child development indirectly. This seems reasonable because children spend most time in their family environment, and more than one child can benefit from a family-oriented approach. However, recent evaluation of a 21-site, federally funded demonstration project confirmed what has been consistently reported in the research literature: family- or parent-oriented programs do not affect child developmental outcomes. The Comprehensive Child Development Program (CCDP) was administered by the Administration on Children, Youth and Families with a budget of $25 million per year for three years. Participating sites provided comprehensive services with the goal of intervening early in the lives of young children. A variety of services were provided, but the CCDP did not include direct child education components. Instead parents were provided with information and support regarding issues of child development and parenting skills. Data were collected yearly on over 100 outcome measures. The final estimate of cost per family over the 3 years was $47,000. The evaluation of the program was unequivocal: the CCDP had no effect on cognitive or socio-emotional development of children, parenting skills, or family status (49). This project clearly illustrates the need for randomized, controlled trials for child development interventions, with a strong evaluation component built into the project.

THE ROLE OF THE EARLY SOCIAL ENVIRONMENT

The emphasis on the current discourse has been on the relation of brain development to cognitive and educational outcomes. However, an increasing body of literature with equal relevance to public health involves early regulators of later social and affective development. Aggressiveness, poor inhibitory control, and lack of attentiveness are developmental outcomes that impinge on the lives of children as well as affect the larger society. Although these studies are often subsumed under the "new brain research" rubric, methodologies involve behavioral and traditional psychobiologic approaches, not brain imaging.

Adults provide the social and emotional environments of infants. These earliest relationships have been referred to as "hidden regulators" of physiologic parameters including cardiovascular, metabolic, endocrinologic, and immunologic function, as well as behavior (27). Early social experiences are believed to affect homeostatic control in a variety of centrally directed systems, particularly the hypothalamic-pituitary-adrenal (HPA) axis. Such effects can be far reaching, affecting not only development during childhood, but characteristics such as susceptibility to disease in adulthood. A series of studies in rats by Meaney and

colleagues has illustrated the potent effect that early social interactions have on HPA axis regulation by exposing rat pups to exogenous stressors and variants of maternal care. Maternal care in the first ten days of life that is characterized by high levels of licking and grooming behavior is associated with reduced responses to a stressor (i.e. temporary restraint) in adulthood. In comparison to animals who received low levels of "nurturance," high maternal care was associated with reduced secretion of ACTH and corticosterone in response to stressors, as well as enhanced glucocorticoid feedback responsivity to priming the HPA through corticosterone injection (34). In addition, correlational analyses revealed linear associations ($r = 0.76$) between levels of maternal caretaking behaviors and genetic (i.e. mRNA) mediation of neuroendocrine responses, providing a well-defined example of the role of the environment in genetic expression. On a behavioral level, offspring who receive high levels of maternal care also exhibit less fear to novelty and greater exploratory behaviors in open field conditions. Similar findings regarding alterations in the HPA axis as a function of maternal-infant relations have been observed in nonhuman primates as well (12).

It is not news that temporary or prolonged separation of offspring from mothers produces profound effects on physiology. What distinguishes these studies, and others like them, is the demonstration that the quality of care received by infants within the normal range of a species also has long-lasting effects on multiple physiologic systems. Moreover, there is intergenerational transmission of parenting behavior. High maternal care of offspring is associated with high maternal care by those offspring when they produce young. This effect persists even when genetically bred litters are cross-fostered. That is, when offspring of low maternal care strains are provided with mothers that exhibit high maternal care, those offspring provide high maternal care as adults, in contrast to their genetic make-up. This effect is considered to provide evidence of nongenomic transmission of traits and is supported by biochemical analysis across the HPA axis spectrum (17).

Most of the data supporting the role of early nurturance is derived from animal research, where such relationships can be experimentally manipulated. The behaviors important in nurturing a litter are very different from those expressed by human mothers, so caution against overgeneralization must be exerted. As with brain imaging studies described in earlier sections, such studies can significantly aid in understanding mechanisms which guide behavior. However, there are converging and robust data from child development research to support a role between the quality of early parental care and neuroendocrinological and behavioral responses to stress (20). Stress research in children must rely on naturally occurring physical stressors or relatively mild laboratory-based novel or fearful stimuli. Dependent measures typically include basal and reactive cortisol levels as well as behavioral responses. When toddlers are exposed to a series of novel arousing stimuli, only children who display indicators of insecure attachment to their mothers respond with an increase in cortisol level to the challenge. In contrast, toddlers with more secure relationships are more likely to exhibit behavioral indicators of coping ability in the new situation (37). Similar results have been

observed in response to immunizations in early infancy. During acute and invasive stressors such as this, mothers of securely attached children can provide effective comforting techniques that dampen cortisol responsiveness. The concept of attachment is a central tenet of early child development. Healthy relationships with parents provide children a secure affective base, allowing them freedom to explore their environment, which in turn, fosters development. This recent line of investigation suggests that attachment does much more, that it provides an early buffer or regulator of the HPA axis response to threat or challenge. The functioning of this system and its influence on other areas of the brain is complex, but early factors that alter its homeostatic balance are presumed to have long-lasting effects on HPA hypo- or hyperactivity (9). Studies of HPA activation and behaviors in infants and children exposed to early trauma or disordered parenting relationships, including maltreatment, yield converging evidence.

Research on the influence of parenting styles on child outcomes has produced some consistent results. In general, caregiving that is contingent, responsive, and characterized by warmth is associated with development of children's ability to self-regulate, while punitive styles of parenting, characterized by harsh treatment and lack of warmth, have been associated with patterns of poor impulse control. The research literature relating parenting style to later outcomes is not as extensive as that of early attachment and is often based on theoretical frameworks of socialization and cultural beliefs without extensive empirical confirmation. However, data generated by psychobiologic studies provide a potential mechanism for these associations. Children who are commonly frustrated or negatively aroused as a result of punitiveness or parental unresponsivity may display chronic patterns of elevated cortisol. Cortisol has specific effects on the glucocorticoid receptors in the association neurons in the frontal cortex. This region is of particular significance because of its influence on executive and self-regulatory functions. Confirmation of the role of specific parenting strategies in altering the HPA axis awaits further investigation.

CONCLUSIONS

Although both neuroscience and developmental psychology have long histories, synthesis using knowledge and techniques from each is in its infancy. Brain imaging techniques provide the opportunity to understand the mechanisms governing development, and behavioral research provides validation for supposition of brain function. Science moves slowly, and is built on replication and elaboration. The public demand for strategies to improve child outcomes has immediacy. Take, for example, the many programs now promoting reading to infants and young children as a critical medium for academic success. However, there are no developmental studies on the effect of early exposure to reading on later outcomes, including early initiation of reading. Nor would it be easy to implement the randomized controlled trial that would provide the only definitive evaluation. Should we dissuade parents

from reading to their children? Of course not. Nor should we continue to insist that engaging in this practice will produce early or better readers in the absence of data. Instead, reading to children has many positive attributes including exposure to complexities of grammar and vocabulary, which has been independently shown to be associated with linguistic and cognitive development (21). Perhaps more importantly, this practice has implications for promoting parent-child interaction by providing a period of joint focused attention, investment, and nurturance. The number of adult and child-oriented reading materials differs dramatically on the basis of social class, and child-centered literacy has been identified to be an important feature of the educational goals and expectations of families (26). There is also evidence that encouraging reading activities in low SES families is amenable to intervention (25). Nonetheless, it remains incumbent upon public health practitioners to acknowledge where the data end and advocacy begins.

In a publication relating information about early brain development to child care, The American Academy of Pediatrics (1) advocates the following for young children:

- Nurturing, supportive, secure, predictable relationships.
- Individualized and responsive care and attention.
- A stimulating learning environment that includes exposure to good language models.

It is hard to argue with these tenets, despite the fact that they are not at all informed by findings from brain research. Hi-tech images of the brain have captured public and political attention in a way that decades of study of child behavior rarely has. The public health relevance of the new brain research is far from apparent, but the spotlight has cast a wide beam. Within it, the accumulating research literature concerning the role of early social relationships in later self-regulatory and coping behaviors through the mediation of the HPA axis, in tandem with the expanding nature of behavioral problems currently evidenced by children, should serve to bring the importance of affective development and self-regulatory processes to the forefront of public health. Current concerns regarding youth violence, anger, and poor impulse control are paramount. Children are exposed to developmentally inappropriate stimuli from a variety of sources and many parents lack strong bonds with their children. In addition to these risk factors, which cut across all social classes, childhood poverty and low parental educational attainment compound their effects. In the 1990s, 17% of children lived with mothers without a high school education (23). Efforts to salvage the disappointing history of early intervention programs, including Head Start, by acclaiming small effects mask the immense consequences of poverty on children.

Although the interest in early infancy is gratifying to those of us who study infants, no single period of development is more important than another. Channeling resources and interest away from older children and adolescents to promote early development would be a lamentable consequence of the new brain research.

Rather, consideration of the plasticity of the human brain and the resilience of children burdened by deleterious physical and social environments should guide public health applications across all ages.

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